The SIM Astrometric Grid

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The SIM Astrometric Grid

- **Purpose**
  - Our Only Calibration of the Instrument
  - Reference Mechanism for Science Measurements
    - Supplies reference for Science Object position
    - Used for determining the Baseline during data-taking
- **Content**
  - *O*(3000) Stable Stellar Objects distributed somewhat uniformly over the Celestial Sphere
  - *O*(100) QSO's to establish Extragalactic Tie

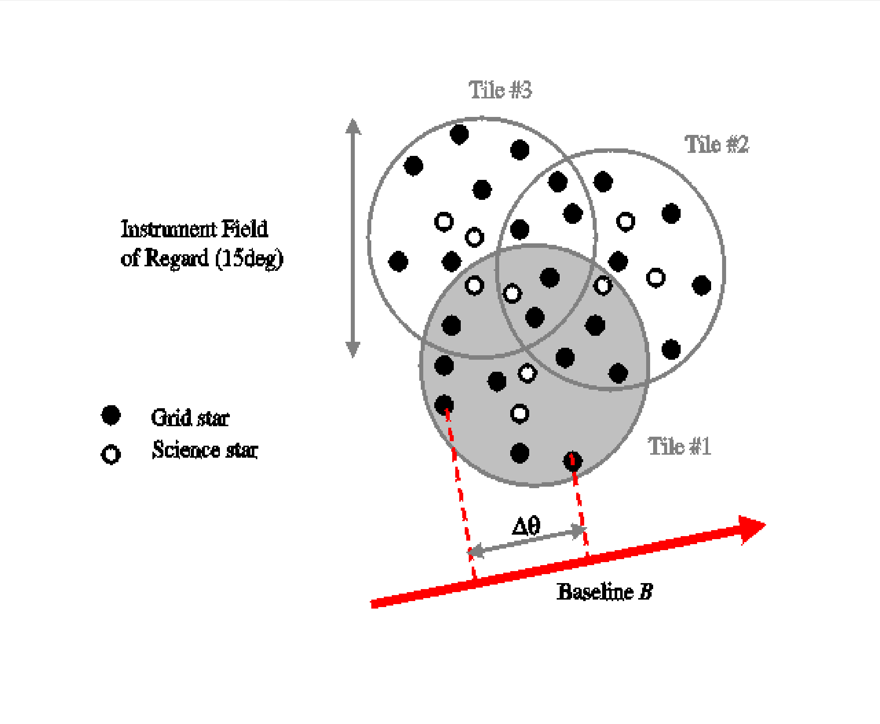
The Astrometric Grid

- SIM doesn't directly measure position or separation, all measurements are *delays,* one object at a time

$$d = s \bullet B + C + errors$$

  - *where:*
    - d = *delay measurement*
    - s = *object unit 3-vector*
    - B = *Baseline 3-vector*
    - C = *internal offset for inherent path length differences*
- By bringing together many of these 1-d measurements, along with some a priori information on object positions, we can fit for the grid

The Grid Observations



- O(3000) Objects
- Individual Measurements are 1-d delays, *not separations*
- About 1/2 tile overlap
- ~1000 15º tiles per scan (solar exclusion of 45º)
- ~12-15 grid objects per tile

Developing the Astrometric Grid

- All Grid Objects repeatedly sampled during Mission to scan the whole sky ~4.5 times a Year.
- Object Measurements are done serially
  - Common Baseline Orientation during a single field-of-regard (which we call a "***tile***") ties delay measurements together for that tile.
  - Objects in tile overlap regions tie the tiles together for the 4π Grid
  - Celestial Sphere surveyed twice per Scan with Quasi-Orthogonal Baseline Projections to obtain Isotropic Position Errors.

The Astrometric Grid

- Thus, our observables are a series of delay measurements (and low-resolution baseline estimates) and a perturbed star catalog. From this, all we have to do is calculate a maximally consistent map of the universe.

Sequence of the Grid Simulation

- Generate O(3000) random *truth* objects
- Perturb *truth* objects to form *knowledge* objects
- Define grid scan campaign sequence
- Simulate delay measurement using *truth* catalog
- Use understanding of instrument to form Design Matrix
- Use *knowledge* catalog as our first *a priori* grid model
- Iterate a solution

The Design Matrix

- From the astrometric equation, we form a design matrix containing the details of the instrument performance as we understand it. This includes the way that the model parameters affect the results
  - Astrometric parameters $\alpha, \delta, \mu_\alpha, \mu_\beta, \pi$
  - Baseline length and attitude
  - Effects we can model (focus of some current studies)
  - Stellar aberration
  - gravitational lensing from Sun, Jupiter

Solving the Grid

- Converge on a maximally consistent grid by iterating on
  - *min|**Ax** - **b**|*
  - where
    - *A is our design matrix*
    - *x is a correction vector of the parameters*
    - *b is a vector of the differences between the observable delays:*

$$\boldsymbol{b_i = d_i - (s_i \bullet B + C)_{model}}$$

- Problem: The design matrix is large (100k x 100k) and sparse, so direct inverse is prohibitive for simulations and studies

Solving the Grid

- We exploit the sparseness of ***A*** by solving the associated set of normal equations:

$$(A^T A)x = A^T b$$

- Find an approximate solution using the method of Conjugate Gradient on the Normal Equations. This approximation to the correction vector, ***x*** is then applied to the model and the procedure is reiterated
- Convergence usually occurs within 16-18 iterations
- This doesn't give a covariance matrix, but we can empirically approximate one when needed

Current Status of Grid Studies

- Simulation Fidelity
  - Ability to vary scan model (timing of tile observations)
  - Magnitude (fringe finding) uncertainties
  - Baseline metrology drifts enabled (including breaks)
  - Recently added multiple “pin objects”
- Completed Studies:
  - Metrology breaks between tiles (more robust than we thought)
- Current Studies:
  - Metrology Drifts within a tile:
    - Time dependent - thermal
    - Angular dependent - less than perfect optics
  - Non-Simple Grid Objects

Grid Object Selection

- Magnitude ~12
- Evenly distributed
- Simple Objects with linear Astrometric parameters
- Barycenter = Photocenter
- A range of distances
- Ability to study the object with ground-based measurements